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E. W. HILGARD, DIRECTOR

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Methods of Physical and Chemical Soil Analysis.

BY E. W. HILGARD.

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Before entering upon the details of physical and chemical soil investigation, it may not be superfluous to define what are the objects to be accomplished in such investigations, both from the standpoint of the farmer and of the agricultural expert.

It is well understood that in the present state of knowledge, the chemical analysis of soils long cultivated and fertilized affords, alone, but a limited amount of information regarding their productiveness, although always useful in defining their general character and obvious deficiencies. In the case of those cultivated without fertilization, even for a considerable length of time, chemical analysis will afford us valuable indications not only regarding their general character, but also in respect to the important soil ingredients most likely to have been reduced below the level of profitable culture. Yet, so long as virgin spots fairly representing cultivated lands exist, the results obtained by the examination of the former can be fruitfully applied to the latter.

In virgin soils the indications, as experience has shown, become so definite as to permit a close forecasting not only of the general character and value of lands not yet brought under cultivation, but also of their best adaptations and of the probable duration of productiveness without fertilization. Chemical analysis can thus, when combined with the physical, geological, and botanical examination of soils, give information of such direct practical importance, that in the newer States and in the Territories it becomes a reliable guide to the settler in the choice of lands and cultures. Such work is therefore peculiarly the province of the experiment stations west of the Mississippi River.

As regards physical soil analysis as practiced in Europe, its results have fallen far short of the expectations which, theoretically, it might be expected to fulfill, viz., the definite measurement of the "tilling qualities" and of other physical coefficients of soils. The judgment regarding these points deducible from the great majority of mechanical soil analyses as usually made and published, affords hardly more information than could be derived from mere hand tests on the dry and wet soil. Yet it is hardly doubtful that a proper study of the physical composition can be made to yield a much deeper insight into the functions of the several physical soil ingredients and, consequently, into the means of modifying the physical properties to the best advantage.

One important function of such examinations (about the feasibility of which there can be no reasonable question) is the identification of uncultivated soils with those of lands already under cultivation, thus permitting the application to new lands, of experience already acquired. But in order to attain such results, not only must the mode of sampling in the field, the preparation of the samples for analysis, and the physical and chemical analysis itself, be conducted upon a well-considered and uniform system, but the conditions of occurrence, the "lay," depth, climate, natural vegetation,

etc., must be known as fully as possible, since all these factors must be taken into consideration in interpreting, for practical purposes, the results of the physical and chemical examination. Moreover, in determining the conditions to be fulfilled and the *modus operandi*, all arbitrary conventions should be avoided as much as possible, since all such are sure to be violated, sooner or later, by workers who consider themselves as much entitled to exercise of judgment as any one else. In developing the methods originally suggested by D. D. Owen, it has therefore been sought to establish a rational basis inherent in the nature of the case, as far as possible, and to determine maxima or minima rather than arbitrarily assumed means. The detailed motivation of all these points would increase this report far beyond the admissible limits; but references are given to the publications in which such points are discussed.

For brevity's sake a detailed description of the manipulations in the case of well-known analytical methods is omitted, mentioning only some critical points upon which success depends, but taking for granted the following out of the accepted precepts.

THE SAMPLING OF SOILS.

Since the practical utility of soil work would be greatly impaired were it dependent only upon the personal exploration of the wide domain by the experiment station officers, I have formulated, and long used successfully, the following "Directions for taking Soil Samples," that are forwarded either to persons desiring information as to their lands, or to intelligent farmers residing in regions of which the soils are to be investigated. It is often surprising how accurate and graphic are the data so obtained.

In taking soil specimens for examination the following directions should be carefully observed, always bearing in mind that the analysis of a soil is a long and tedious operation, which can not be indefinitely repeated:

(1) Do not take samples indiscriminately from any locality you may chance to be interested in, but consider what are the two or three chief varieties of soil which, with their intermixtures, make up the cultivable area of your region, and carefully sample these first of all; then sample your particular soil with reference to these typical ones.

(2) As a rule, and whenever possible, take specimens from spots that have not been cultivated, nor are otherwise likely to have been changed from their original condition of "virgin soils"—*e. g.*, not from ground frequently trodden over, such as roadsides, cattle paths, or small pastures, squirrel holes, stumps, or even at the foot of trees, or spots that have been washed by rains or streams, so as to have experienced a noticeable change, and not to be a fair representative of their kind.

(3) Observe and record carefully the normal vegetation, trees, herbs, grass, etc., of the average land; avoid spots showing unusual growth, whether in kind or quality, as such are likely to have received some animal manure or some other outside addition.

(4) Always take specimens from more than one spot judged to be a fair representative of the soil intended to be examined, as an additional guarantee of a fair average.

(5) After selecting a proper spot, pull up the plants growing on it and brush off the surface lightly to remove half-decayed vegetable matter not forming part of the soil as yet. Dig a vertical hole, like a posthole, *at least* 20 inches deep; in arid regions, not less than 36 inches. Scrape the sides clean so as to see at what depth the change of tint occurs which usually marks the downward limit of the surface soil, and record it. Take at least half a bushel of the earth above this limit, and on a cloth (jute bagging should not be used for this purpose, as its fibers, etc., become intermixed with the soil) or paper, break it up and mix thoroughly, and put up *at least a pint* of it in a sack or package for examination. This specimen will, ordinarily, constitute the "soil." Should the change of color occur at a less depth than 6 inches the fact should be noted, but the specimen taken to that depth nevertheless, since it is the least to which rational culture can be supposed to reach.

In case the difference in the character of a shallow surface-soil and its subsoil should be unusually great—as may be the case in tule or other alluvial lands or in rocky districts—a separate example of that surface soil should be taken, besides the one to the depth of 6 inches.

(6) Whatever lies beneath the line of change, will constitute the "subsoil." But should the change of color occur at a greater depth than 12 inches the "soil" specimen

should nevertheless be taken to the depth of 12 inches only, which is the limit of ordinary tillage; then another specimen from that depth down to the line of change, and then the subsoil specimens beneath that line.

The depth down to which the last should be taken will depend on circumstances. It is always necessary to know what constitutes the foundation of a soil, down to the depth of 3 feet at least, since the question of drainage, resistance to drought, etc., will depend essentially upon the nature of the substratum. But in ordinary cases in the humid region, 10 or 12 inches of subsoil will be sufficient for the purposes of examination in the laboratory. The specimen should be taken in other respects precisely like that of the surface soil, while that of the material underlying this "subsoil" may be taken with less exactness, perhaps at some ditch or other easily accessible point, and should not be broken up like other specimens, so as to preserve, *e. g.*, the character of "hardpan"

In the arid regions, where surface soil and subsoil are very much less definitely differentiated, and the depth of the soil mass is usually very great, it is in most cases advisable to take samples representing the average of each foot, from the surface down to 4 or 5 feet; or even more, according to circumstances.

(7) Specimens of salty or "alkali" soils should, when practicable, be taken toward the end of the dry season, when they will contain the maximum amount of the injurious ingredients with which it may be necessary to deal.

Since ordinarily the alkali salts are contained mainly within the first 4 feet below the surface within which the salts descend or rise according to the seasons, it will for practical purposes mostly be sufficient to take an average sample of a 4-foot column, the leaching of which will indicate the kind and amount of salts to be dealt with. But the last portions brought up by the soil auger should at least be cursorily examined for their salt content, and therefore sent separately. In some cases it will be desirable to sample each foot of the column separately.

(8) All peculiarities of the soil and subsoil, their behavior in wet and dry seasons, their location, position—every circumstance, in fact, that can throw any light on their agricultural qualities or peculiarities—should be carefully noted and the notes sent with the specimens. Unless accompanied by such notes, specimens can not ordinarily be considered as justifying the amount of labor involved in their examination.

It will be noted that in these "directions" the depth of the surface "soil" sample to be taken is left to the judgment of the farmer, between the limits of 6 and 12 inches, the first being the minimum, the latter the maximum, depth to which rational culture usually reaches.

When the soil sample is to be transmitted to any considerable distance it is very desirable that it should be dried in the sun as completely as possible before shipment, since otherwise not only does it often arrive in an abnormally puddled and compacted condition, but may become moldy, changing the natural condition not only of the organic but also of the reducible inorganic ingredients; notably that of ferric hydrate and nitrates. With respect to the latter the date of taking the sample is also desirable and should be recorded in every case.

THE MECHANICAL OR PHYSICAL ANALYSIS OF SOILS.

The "insoluble residue" of the chemical analysis indicates in a very general manner the amount of "sand" in a soil; and when combined with a determination of the soluble silica, alumina, and lime we also gain some idea of possible plasticity or "heaviness." But these indications given by chemical analysis are far too indefinite for practical requirements It is to the mechanical (or physical) analysis that we must look for practically available data on the tilling qualities of soils; but the loose practice mostly prevailing thus far has rendered the results far from satisfactory.

PRELIMINARY EXAMINATION.

The first step toward the determination of the character of a soil sample should always be what might be termed the *hand tests*, to wit, the observation of the greater or less degree of ease with which the soil lumps crush between the fingers in the dry condition; the presence or absence of coarse sand, etc.; also the change of color on wetting,

the degree of rapidity with which the water is absorbed, the extent to which it softens the lumps, and the degree of plasticity assumed when the wet soil is kneaded.

The next step should be the at least approximate *identification of the minerals* forming the coarse portion, since it must be presumed that, as a rule, these represent the original nature of the fine grains also. We thus already gain a very close insight into the origin and general character of the soil. This mineralogical examination is advantageously combined with an approximate quantitative determination of the coarse portion by sedimentation in a small beaker, or more advantageously, by means of a "Kühn's cylinder" and an upward current of water of definite velocity; that of 2 mm. per second is convenient for this purpose, provided that the sample is kept stirred by means of a rod. The dried coarse portion is weighed and then examined with lens and microscope, with or without previous separation by means of Thoulet's or some other dense fluid. This examination is of especial value in the identification of the sample with other soils previously investigated, and thus frequently saves a very large amount of analytical labor.

When the preliminary examination does not suffice for the purposes in view, and detailed mechanical or "silt analysis" must be resorted to, more elaborate and complex methods and appliances are called for.

SEDIMENTATION AND HYDRAULIC ELUTRIATION.

In a general way a soil may be considered as consisting of clay intermixed with more or less mineral powder or sand of various grades of fineness, together with some humus or vegetable mold. The two former usually determine, in the main, the tilling qualities of the soil.

As regards, first, the conventional "clay" which figures in the analytical statements, *e. g.*, of the German investigators, it oftentimes consists far more of fine silex than even of total kaolinite substance. Since the latter itself consists at least of two portions totally distinct in their physical functions, viz., of chalky crystalloid grains and of a "colloidal," highly diffusible, and extremely adhesive and hygroscopic portion, the presence of which determines, in the main, the corresponding physical properties of the soil, the indefiniteness of the current mode of statement and consequent classification of soils is so great as to render a clearer and more rational and definite method of mechanical analysis absolutely necessary from this point of view alone. An additional source of error arises from the viscosity and consequently greater hydraulic efficacy of "clay water," which carries off, at the same velocity, much larger particles of rock powder than does pure water; or in the case of subsidence, permits them to settle much more slowly. The consequence is that the percentage of a sediment of a given "hydraulic value" will be found very different, according to the amount of colloidal clay present, or according as the latter has or has not been wholly or partially removed prior to the separation of the simply pulverulent or sandy ingredients. Adding to these sources of uncertainty the wide range of size of grain included and weighed as one sediment by most observers, the slight value attaching thus far to the results of mechanical soil analysis as representing the farmer's experience is amply explained.

For the separation of fine powders and mixed grain-sizes, sedimentation by stirring up in water and drawing off the suspended sediment with the water after a definite time allowed for the subsidence of the coarser portions is, of course, the simplest process, which has been used in the arts and in pharmacy for centuries. For analytical purposes it has the disadvantage that in order to effect a reasonably complete exhaustion of a sediment of a definite size or "hydraulic value," the operation of stirring up and drawing off must be repeated a large number of times, since the time of subsidence is reckoned for the top layer of water, while subsidence actually occurs from below as well. The subsidence method requires close and continuous attention in its execution for a length of time proportioned to the minuteness of subdivisions desired; moreover, in the case of fine sediments, which have a tendency to coalesce (flocculate) under the action of the irregular currents caused by stirring, the difficulty of obtaining them properly segregated is almost insuperable, greatly detracting from the accuracy of the determinations. The subsidence or (as it has lately been termed) "beaker" method, however convenient on account of its simplicity, is therefore ill adapted to the carrying out of extended investigations requiring the performance of a large number of mechanical soil analyses,

and its laboriousness has long caused it to be replaced, in European practice, by various devices embodying, in a more or less perfect form, the idea of separation of grain-sizes by an ascending current of water, or "hydraulic elutriation." The writer's personal experience has brought him into full sympathy with this view.

When, in 1872, the writer began the consideration of this subject in connection with the agricultural survey of the State of Mississippi, even a very superficial test led him to reject quickly the grossly inaccurate and misleading apparatus of Nöbel, with its four vessels of ever-varying capacity and form and inconstant head of water. The best then known, that of Schöne, proved much more satisfactory, provided the "colloidal clay" was first removed. But even then there remained a large and variable residual error, shown in the mixed grain-sizes of the sediments and correspondingly varying percentage results. A protracted investigation of the causes of these inaccuracies, made in the years 1872 and 1873, and published in the latter year,* proved that the great difficulty encountered in the separation of soil ingredients by the ordinary methods of sedimentation heretofore employed has been in the strong tendency of the fine particles to coalesce into large, compound floccules, and settle with the coarser sediments. When violently shaken they part company and become diffused singly through the liquid, which then presents simply a general turbidity; the particles then settling down slowly and singly at the rate corresponding to their individual size or hydraulic value.

The following experiment, well suited to the lecture table, serves to demonstrate the above principle: If a given quantity of pure siliceous sediment of, *e. g.*, 1 mm. hydraulic value (which has therefore been carried off at the velocity of 1 mm. by an ascending current of water) be again placed in the same current, in a long conical tube with cylindrical outlet above, a considerable portion will fail to pass off, and will gather into flocculent aggregates, revolving in the lower (narrow) part of the tube. If instead of the full velocity of 1 mm. only 0.8 mm. is used, none of the sediment will pass off, but after some time it will be found wholly gathered together into the heavy flocculent aggregates, when the full velocity of 1 mm. may be used without causing any considerable portion of sediment to be carried off, until by violent stirring with a rod the floccules are destroyed. It is only, however, by repeating this outside stirring a number of times, that it is possible to get nearly all the sediment corresponding to the velocity of current actually used to pass off. The stirring by the current itself is powerless to do so, because the return currents down the sides of a conical tube perpetually cause recoalescence or "flocculation."

It is thus clear that even with purely siliceous and nonglutinous sediments correct results can not be obtained so long as conical elutriator tubes are employed; and this effectually bars the claims of, *e. g.*, Schöne's apparatus (now adopted by the German experiment stations), to the accuracy desirable in this work.

But if cylindrical elutriator tubes are alone admissible, then it follows that agitation by outside power, for keeping the soil or powder in suspension and continuously resolving the floccules inevitably formed under the circumstances, is indispensable. However, the tendency to coalescence diminishes of course as the size of the grains increases, but does not altogether cease until their diameter exceeds 0.2 mm., or about 16 mm. hydraulic value. For the elutriation of coarser sediments hydraulic stirring may be successfully employed.

We may therefore formulate as follows the conditions to be fulfilled by mechanical soil analysis upon which definite conclusions as to the physical and agricultural (or "working") qualities of soils, and of the functions of the several grain-sizes in determining the same, may be based:

(1) The preliminary preparation of the soil sample must leave its natural physical condition unimpaired. It must, therefore, not be heated to any temperature likely to wholly or partially dehydrate any of its constituent colloids; nor must it be triturated or "pestled" in any manner likely to destroy the naturally existing aggregates or floccules cemented by lime carbonate, ferruginous, zeolithic, or other cements; nor must the latter be dissolved by the use of acids, thus changing the natural aggregates into a multitude of fine particles which do not exist in the original soil, and perform

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*Amer. Jour. of Sci., Oct., 1873; Proc. Amer. Assoc. Adv. Sci., Portland meeting, 1873. See also "The Flocculation of Particles," Am. J. Sci., March, 1879.

the physical functions of sand grains of corresponding size. Boiling the soil is free from these objections.

(2) Prior to any attempt to separate the different grain-sizes, whether by the hydraulic or subsidence method, the "colloidal clay" must be completely removed; and in view of the prime importance of the latter as a physical soil ingredient it must be determined by direct weighing, and not merely by loss, or "difference"

(3) If the hydraulic method be used for the separation of the successive grain-sizes this must be done in vertical, cylindrical elutriator tubes, provided with a device for mechanical stirring by outside power, for preventing and undoing the flocculation of the sediments into heavy aggregates of indefinite composition and hydraulic value.

(4) The importance of discriminating between the several fine sediments in respect to their physical functions is so great that a much larger number of subdivisions of these must be made than is now usually done. This proviso renders the ordinary process of sedimentation by stirring and subsidence in cylindrical vessels (beaker method) practically inapplicable to any extended investigations requiring frequent and numerous mechanical analyses, since each one would take an amount of time and practice quite out of reach of ordinary laboratory personnel. The work must in the main be done automatically to be generally available.

The ways and means by which these several conditions may most easily be fulfilled will now be considered in detail.

PRELIMINARY PREPARATION.

In some cases simple sifting will serve, without further preparation, to separate the original, dry soil sample into appropriate subdivisions, down to the fine earth that is to serve for detailed mechanical and chemical analysis. In most cases, however, a certain amount of mechanical disintegration must be resorted to in order to detach the earth from the larger sand grains and aggregates, and here some judgment must be exercised by the operator. A preliminary washing, aided by the lens and microscope if necessary, will show whether there are any soft concretions or decomposed rock particles likely to be crushed by a rubber pestle, the hardest material admissible, but which will serve admirably when no soft grains will be crushed by it, thus changing the nature of the soil to a corresponding extent. The liability to such change is much increased by wetting the soil, when calcareous and ferruginous concretions (bog ore) may be crushed to such extent as to destroy the value of the work. In the case of heavy clay ("adobe") soils, however, wetting, and even hot digestion with water, may be necessary to even the preliminary disintegration serving to prepare a fair average sample. The slushy mass must then be economically washed through the fine-earth sieve and the remnant afterwards separated into sizes by sifting, while the fine-earth slush is evaporated and dried to serve for analysis.

Since a sieve with 0.5 mm. mesh is practically about the finest that will serve for the dry separation with advantage, and since that same diameter is almost exactly that of quartz grains passing off at the maximum current-velocity conveniently available, viz., 64 mm. per second, the writer has adopted the 0.5 mm. limit as practically the best for the fine earth to be used for both mechanical and chemical analysis. It is to such fine earth that the data hereinafter given are meant to apply.

DISINTEGRATION BY BOILING.

This is applicable to all soils, the time required varying greatly with different ones. Those containing much lime carbonate require the longest time to resolve those aggregates which will be also destroyed by tillage. Further than this the disintegration should not go; nor should it fall seriously short of that normal measure. Thirty hours have in one case barely sufficed for a black calcareous prairie soil, while three have been found sufficient to reduce other soils to clean, single grains, as observed under the lens. While an absolute rule can not therefore be given, it may be said that with most soils from eight to fifteen hours will be the right measure, which with some may extend to twenty and twenty-four. The fact ascertained by Osborne, that the diffusibility of some clays, at least, is diminished by long boiling, renders it desirable to restrict its duration to a minimum.

The boiling is best done in a thin, long-necked copper or glass flask of about 1 liter capacity, filled four fifths full of distilled water and laid on a stand, on wire netting, at an angle of 40° to 45°. It is provided with a cork and condensing tube of sufficient length (5 to 6 feet) to condense all or most of the steam formed when ebullition is kept up by means of a gas flame. For a few hours the boiling generally proceeds quietly; but as the disintegration progresses violent bumping sets in, which sometimes endangers the flask, but is of assistance for the attainment of the object in view. In extreme cases some of the heavier sediment (gėnerally clean sand) may be removed from the flask, but this is undesirable.

It is frequently the case that when the boiled contents are left to settle, the liquid appears perfectly clear within an hour, although so soon as they are largely diluted the clay becomes diffused as usual, and will not settle in weeks. Probably this is owing to the extraction from the soil of soluble salts, which exert the same influence as does lime or common salt, even in very dilute solutions.

REMOVAL OF THE COLLOIDAL CLAY AND FINEST SEDIMENTS.

The boiled fluid with sediment is transferred to a beaker and diluted so as to form from 1 to 1½ liters in bulk, and being stirred up, is allowed to settle for such a length of time as (taking into account the height of the column) will allow all sediments of 0.25 mm. hydraulic value to subside, the process being repeated with smaller quantities of water (distilled) until no sensible turbidity remains after allowing due time for subsidence.

It must be remembered that this time is considerably longer than that for pure water, so long as any considerable amount of clay remains in the liquid, rendering it more viscous. And as the precise amount of allowance to be made can not in general be foreseen, some sediment of and exceeding 0.25 mm. hydraulic value, will almost inevitably be decanted with the successive clay waters, until the buoyant effect of the clay becomes insensible. The united clay waters (of which there will be from 4 to 8 liters) must therefore be again stirred up, and the proper time allowed for the sediments of 0.25 mm. and over to subside. The dilution being very great, a pretty accurate separation is thus accomplished; the sediments being then ready for the elutriator.

SEPARATION OF CLAY AND THE FINEST SILT IN THE "CLAY WATER."

The now well-known property of colloidal clay, of remaining suspended in pure water for weeks and even months, offers an obvious method of separation from at least the greater portion of silts finer than 0.25 mm. hydraulic value (<0.25). To push this separation to the extreme of attempting to remove all but the kaolinite particles proper, even were it feasible, would carry the time and labor required for the determination beyond the limits required for practical purposes, and would render the performance of mechanical analyses rare events in most laboratories. In special cases, of course, it may be desirable to go to these lengths, and also to divide the sediments lying between the clay proper and the finest sediment that can conveniently be obtained by the hydraulic method (0.25 mm. hydraulic value) into two or more groups, when it is very abundant.

The clay water for subsidence is placed in a wide cylindrical or conical vessel (in which it may conveniently occupy 200 mm. in height); it is there allowed to settle for twenty-four hours. This interval of time was at first arbitrarily chosen, but it was subsequently found to be about the average time required by the finest siliceous silt usually present in soils, to sink through 200 mm. of pure water. So long as any sensible amount of clay is present, the time of course is longer, say from forty to sixty hours, or even more, if the clay be abundant and the liquid not very dilute. The sharp line of separation between the dark silt cloud below and the translucent clay water above is readily observed, and the time of subsidence regulated accordingly. At times, several such lines of division may be seen simultaneously in the column, indicating silts of successive sizes, with a break between. No such appearance is presented when, after weeks of quiet, the clay itself gradually settles. The liquid, which may be almost clear at the surface, then shades off downward very gradually, until near the bottom of the vessel it becomes entirely opaque.

After decantation of the clay water, the remaining liquid is poured off temporarily, leaving the sediment as dry as possible. It is then rubbed or kneaded in the decanting vessel itself, with a long-handled, soft-rubber pestle (conveniently cut out of a rubber cork). At this point the addition of a few drops of ammonia water, according to Schlösing's prescription, renders good service; but it is undesirable to use any large amount of ammonia, as it impedes the subsequent precipitation of the colloidal clay.

Distilled water is again poured on (agitating as much as possible to break up the molecular aggregates) to the proper height, and another twenty-four hours' subsidence allowed. This operation is repeated six to nine times, until either the water remains almost clear after the last subsidence, or the decanted turbid water fails to be precipitated by salt water, showing the suspended matter to be pulverulent silt only.

Doubtless the fine silt obtained in the twenty-four hours' subsidence, the diameter of whose quartz particles varies from 0.001 to 0.02 mm., is not entirely free from adherent colloidal clay, as is indicated by its deeper tint compared with that of the coarser sediments; nor is the "clay" thus obtained free from the finest particles of quartz and especially of ferric oxid; but it is doubtful whether for practical purposes a closer separation, such as was proposed by Williams,* is called for.

The extent to which these contaminations exist, and the distribution of the important soil ingredients among the several sediments, have been discussed in other papers.

Determination of the Colloidal Clay.—The colloidal portion of the kaolinite constituent is of such preëminent importance that to throw upon it the indefinite "loss by analysis" and estimate it "by difference," is hardly excusable. Two ways of determining it directly in the turbid waters from the twenty-four hours' subsidences are open to us. One is to evaporate the whole or an aliquot portion; if the latter is not too small, and the soil is measurably free from the carbonates of lime and magnesia and other soluble salts, this method may yield fairly satisfactory results. But 100 cc. out of perhaps 20 liters of water, as has been practiced by some, is at best a rather minute base line to go upon in so important a determination; moreover, it is so desirable to have the "clay" tangibly before one for examination, that we consider it altogether preferable either to evaporate the entire amount of clay water, which can readily be done *pari passu* with the sedimentation, and then if necessary to extract the soluble portions with water or very dilute acid. I consider it best, however, to precipitate the clay by means of a saline solution and thus weigh the whole. The use of lime water, which naturally suggests itself, is so complicated by chemical reactions and other elements of uncertainty, that I have found it preferable to employ simply pure rock-salt brine for the precipitation. Fifty cc. of a saturated brine, *i. e.*, 1.5 per cent of salt, is ordinarily sufficient to precipitate 1 liter of clay water; the precipitation is much favored by warming. Half the quantity, or even less, will do the same, but more time is required, and the precipitate is more voluminous.

In practice it will be found desirable to thus precipitate each lot of clay water as soon as drawn off. The clay precipitate (which greatly resembles the usual iron-alumina precipitate of chemical analysis) will then at the end of twenty-four hours have shrunk into so small a bulk that on drawing off the supernatant liquid, the succeeding clay water from twenty-four hours' subsidence may be mixed with it, causing it to rediffuse; the same being done at each succeeding drawing off. This mode of operation greatly facilitates and shortens the gathering of the colloidal clay, which is precipitated much less easily and sharply from very dilute waters than from those heavily charged. As the clay precipitate can not ordinarily be washed with pure water, in which it quickly diffuses, it must be collected on a weighed filter, washed with a weak brine, dried at 100° and weighed. It is then again placed in a funnel and washed with a weak solution of sal ammoniac, until the chlorid of sodium is removed. The filtrate is evaporated, the residue ignited and weighed; its weight, plus that of the filter, deducted from the total weight, gives that of the clay itself.

In some cases, especially of clays and subsoils deeply tinged with iron, the clay, after drying at 100°, will not readily diffuse in water, and can be washed with pure water until free from salt; it can then, of course, be weighed directly.

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* Wollny's Forschungen a. d. Gebiete der Agrikulturphysik, vol. 18, p. 225.

Properties of Pure Clay.—The "clay" so obtained is quite a different substance from what usually comes under our observation as such, since its percentage seems rarely to reach 75 in the purest natural clays, 40 to 47 in the heaviest of clay soils, and 8 to 20 in ordinary loams. Thin crusts of it are occasionally found in river bottoms, where clay water has, after an overflow, gradually evaporated in undisturbed pools. When freshly precipitated by salt it is gelatinous, resembling a mixed precipitate of ferric oxid and alumina. On drying, it contracts almost as extravagantly as the latter, crimping up the filter, to which it tenaciously clings, and from which it can be separated only by moistening on the outside, when it may mostly, with care, be peeled off. After drying it constitutes a hard, often horny, mass, difficult to break, and at times somewhat resonant. Since the ferric oxid with which the soil or clay may have been colored is mainly accumulated in this portion, it often possesses a correspondingly dark-brown or chocolate tint. When a large amount of iron is present water acts rather slowly on the dried mass, which gradually swells, like glue, the fragments retaining their shape. Not so when the substance is comparatively free from iron. It then swells up instantly on contact with water; even the horny scales adhering to the upper portion of the filter quickly lose their shape, bulge like a piece of lime in process of slaking, and tumble down into the middle of the filter.

There is a marked difference, however, in the behavior to water of clays equally free from ferric oxid, some exhibiting the phenomena just described in a more energetic manner than others. On the whole, those freest from iron appear to imbibe the water and crumble most readily. As this property possesses highly important bearings, both on the agricultural and ceramic qualities of clays, we propose to investigate it more minutely hereafter.

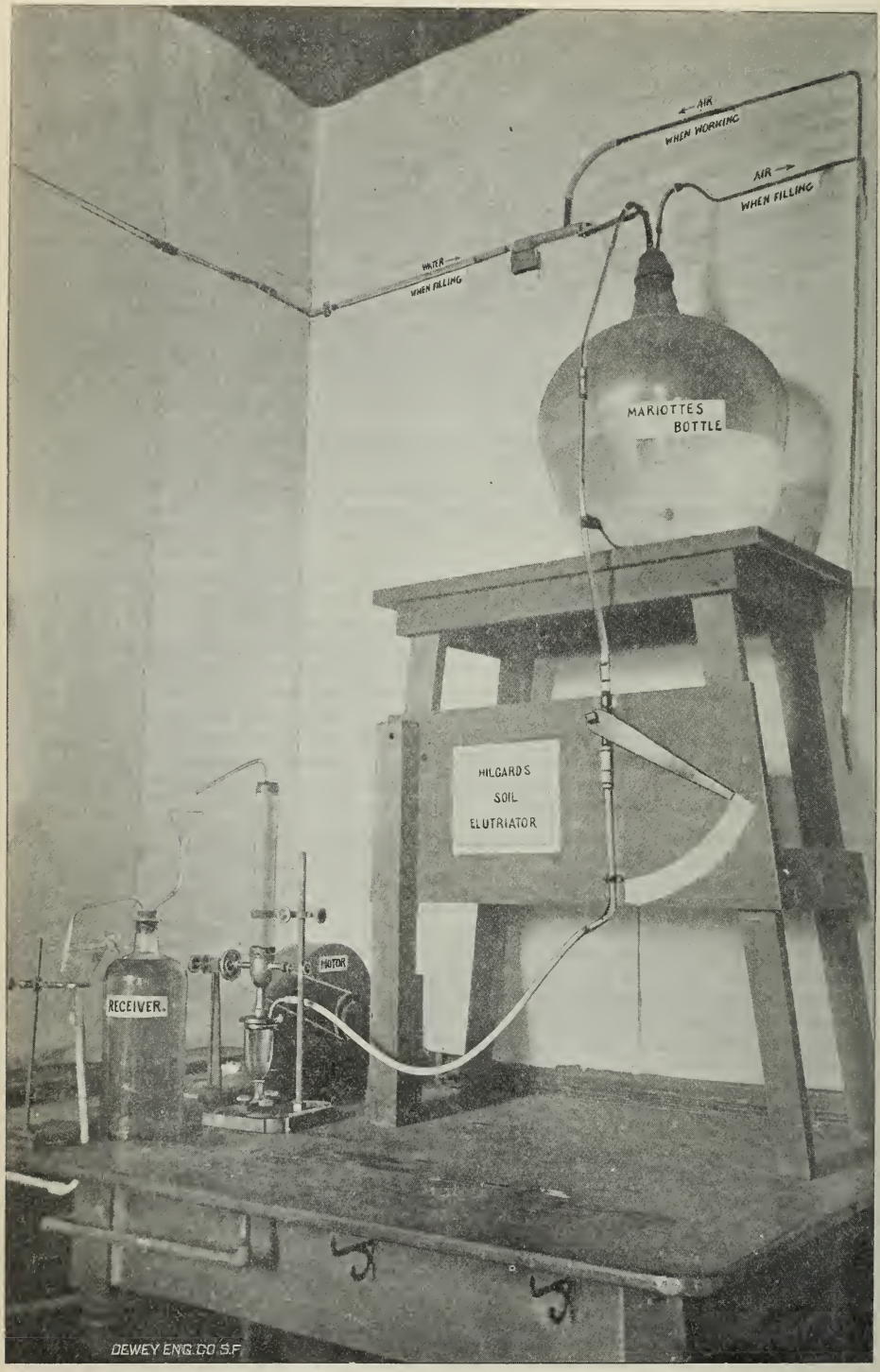
The pure clay, when dry, adheres to the tongue so tenaciously as to render its separation painful. When moistened and worked into the plastic condition, it is exceedingly tenacious and "sticky," adhering to everything it touches.

Under a magnifying power of 350 diameters no definite particles can be discovered in the opalescent clay water remaining after several weeks' subsidence. The precipitate formed by saline solutions then appears as an indefinite cloud (mostly of a yellowish tinge), for which one vainly seeks a better focus. In stronger clay water, or with higher magnifying powers, one can discern a great number of indefinite punctiform bodies, very uniformly diffused throughout the liquid, showing active "Brownian motion," and apparently opaque; the precipitate then formed by brine also shows a faintly dotted structure of its clouds.*

Chemical Nature of the Clay Precipitate.—While usually considered as consisting essentially of kaolinite substance in a state of extremely fine division, the colloidal clay doubtless contains in most, if not in all, cases, other colloidals or "hydrogels," whose absorptive functions (albeit not plasticity) are in a measure similar to those of clay. Since in many cases the silica set free by treatment of the precipitate with acid is materially below that of the alumina dissolved by the same treatment, it follows that free aluminic hydrate is then present. The colloidal ferric hydrate, likewise, is accumulated in the clay precipitate, and so are amorphous zeolitic compounds. While it is thus certain that the most careful mechanical separation of this clay can give only an approximation to the really plastic kaolinite substance, yet such approximation is infinitely closer than that attained by determination of total alumina by boiling sulfuric acid, still sometimes prescribed in text-books. As in such treatment all the chalky kaolinite particles are also decomposed, it does not lead to even the roughest approximate estimate of the soil's plasticity.† It is of late claimed by many that the latter is merely a function of extremely fine subdivision. But no one who has handled the extremely fine portions deposited from the turbid water from quartz mills in the form of "slickens" can fail to appreciate the fact that even though these quartz powders may remain in suspension as long as the clay itself, they do not remotely approach in plasticity even to an ordinary clay. We may be unable to define the physical nature of plasticity, but it certainly does not belong as such to all fine powders, nor to other gelatinous bodies.

* According to Williams and Whitney the finest particles of colloidal clay are 0.0001 mm. diameter. Wollny gives .001 mm. as the limit, stating that the particles have the form of short, straight spicules. Probably the subject is far from its final form as yet.

† See, on these points, my article on "The determination of clay in soils." Agr. Science, 6, 156.


AIR
WHEN WORKING
AIR
WHEN FILLING
WATER
WHEN FILLING
MARIOTTES
BOTTLE
HILGARDS
SOIL
ELUTRIATOR
MOTOR
RECEIVER.
DEWEY ENG. CO S.F

TREATMENT OF THE COARSER SEDIMENTS.

The mixed sediments remaining after the separation of the clay, and of silts of less than 0.25 mm. hydraulic value by decantation, are ready for the elutriator, regarding which some general conditions have already been given; the main point to be guarded being the prevention of the formation of flocculent aggregates out of the granules of the finer sediments.

The Elutriator.—The following is a description of the instrument (see plate) as devised by me for the purpose of breaking up these flocculent aggregates; also of the simpler form (Schöne's elutriator as modified by me), which can serve for grain-sizes above 8 mm. hydraulic value (the latter is conveniently selected as to have half the cross-section of the former, so that with the same position of the index lever the velocity will be just doubled). A cylindrical glass tube, of about 45 mm. inside diameter at its mouth and 290 to 300 mm. high, has attached to its base a rotary churn, consisting of a brass cup, shaped like an egg with point down, so as to slope rather steeply at base, and triply perforated, viz., at the bottom for connection with the relay reservoir; at the sides, for the passage of a horizontal axis bearing four grated wings. This axis, of course, passes through stuffing boxes provided with good thick leather washers, saturated with mutton tallow. These washers, if the axis runs true, will bear many millions of evolutions without material leakage; when a beginning is noted additional washers may be slipped on, without emptying the instrument, until the analysis is finished. From five to six hundred revolutions per minute is a proper velocity for the finest sediments, which may be imparted by clockwork, turbine, or electric power. The driving pulley should not be directly connected with the axis, both because this is liable to cause leakage, and because it is necessary to be able to handle the elutriator quickly and independently. This is accomplished by the use of "dogs" on the pulley and churn axis. For the grain-sizes of 1 to 8 mm. hydraulic value, lower velocities are sufficient. Too low a velocity causes an indefinite duration of the operation, and may be recognized by the increase of turbidity as the velocity is increased.

As the whirling agitation caused by the rotation of the dasher would gradually communicate itself to the whole column of water and cause irregularities, a wire screen of 0.8 mm. aperture is cemented to the lower base of the cylinder.

The relay vessel below the churn of the elutriator tube should be a thick, conical test glass with foot. Its object is to serve as a reservoir for the heavy sediments not concerned at the velocity used in the elutriator tube, and whose presence in the latter, or in its base (the churn), would only cause abrasion of the grains and changes of current velocity, such as occur in the apparatus of Schöne, and compel the current measurement of the water delivered. It is connected above with the churn by a brass tube about 10 mm. in clear diameter, so as to facilitate the descent of the superfluous sediments, which the operator, knowing the proportion of area between the connecting tube and elutriator, can carry to any desired extent, thus avoiding the disturbance of the gauged current velocities as well as all material abrasion.

A glass delivery tube should extend quite half way down the sides of the relay vessel to insure a full stirring up of the coarse sediments when required. By means of a rubber tube, not less than 20 inches in length, this delivery tube connects with a siphon carrying the water from near the bottom of a Mariotte's bottle—a 10-gallon acid-carboy. A stopcock, provided with a long, stiff index lever moving on an empirically graduated arc, regulates the delivery of water through the siphon. Knowing the area of the cross-section of the elutriator tube, the number of cubic centimeters of water which should pass through it in one minute at 1 mm. velocity is easily calculated; and from this the lever positions corresponding to other velocities are quickly determined and marked on the graduated arc. The *receiving bottle* for the sediments must be wide and tall, so as to allow the sediment to settle while the water flows from the top into the waste pipe. The receiving funnel tube must dip nearly to the bottom of the bottle.

Thus arranged the instrument works very satisfactorily, and by its aid soils and clays may readily be separated into sediments of any hydraulic value desired. But in order to insure correct and concordant results it is necessary to observe some precautions, to wit:

(1) The tube of the instrument must be as nearly cylindrical as possible, and must be placed and maintained in a truly vertical position. A very slight variation from the vertical at once causes the formation of return currents, and hence of flocculent aggregates on the lower side.

(2) Sunshine, or the proximity of any other source of heat, must be carefully excluded. The currents formed when the instrument is exposed to sunshine will vitiate the results.

(3) The Mariotte's bottle should be frequently cleansed, and the water used be as free from foreign matters as possible. For ordinary purposes it is scarcely necessary to use distilled water. The quantities used are so large as to render it difficult to maintain an adequate supply, and the errors resulting from the use of any water fit for drinking purposes are too slight to be perceptible, so long as no considerable development of the animal and vegetable germs is allowed. Water containing the slimy fibrils of fungoid and moss prothalia, algæ, vorticellæ, etc., will not only cause errors by obstructing the stopcock at low velocities, but these organisms will cause a coalescence of sediments that defies any ordinary churning and completely vitiates the operation.

(4) *The amount of sediment discharged at any one time must not exceed that producing a moderate turbidity.* Whenever the discharge becomes so copious as to render the moving column opaque, the sediments assume a mixed character, coarse grains being apparently upborne by the multitude of light ones, whose hydraulic value lies considerably below the velocity used; while the churner also fails to resolve the molecular aggregates which must be perpetually re-forming where contact is so close and frequent. This difficulty is especially apt to occur when too large a quantity of material has been used for analysis, or when one sediment constitutes an unusually large portion of it. Within certain limits the smaller the quantity employed the more concordant are the results. Between 15 and 20 grams is the proper amount for an instrument of the dimensions given above.

THE FINE SEDIMENTS (0 25 TO 4 MM. HYDRAULIC VALUE).

It has been found that, practically, 0.25 mm. per second is about the lowest velocity available within reasonable limits of time, and that, by successively doubling the velocities up to 64 mm., a desirable ascending series of sediments is obtained, provided always that a proper previous preparation has been given to the soil or clay. It would seem that, according to the prescription given above for the preliminary sedimentation, no sediment corresponding to 0.25 mm. velocity should remain with the coarser portion. That such is nevertheless always the case, often to a large percentage, emphasizes the difficulty, or rather impossibility, of entirely preventing or dissolving the coalescence of these fine grain-sizes by hand stirring, as in "beaker elutriation." It is only by such energetic motion as is above prescribed that this can be fully accomplished, and the delivery of silts of 0.25 and 0.50 mm. hydraulic value really exhausted.

The operation is best begun by turning on a low velocity, 0.25 to 0.50 mm., and then quickly rinsing the sediments from a small beaker into the elutriator before the column reaches the top. The latter is then quickly closed and a few seconds' subsidence allowed with diminishing velocity, so that the turbid column shall not be within less than 30 mm. of the top when the velocity desired is turned on. Otherwise mixed sediments may pass at the beginning. At first the sediment passes off rapidly, and the column remains obviously and evenly turbid from the point where the agitation caused by the churner ceases to the top. But this obvious turbidity generally exhausts itself in the course of a few hours, and it then requires some attention to determine the progress of the operation. We have never known the 0.25 mm. sediment to become properly exhausted in less than fifteen hours, and in one case it has required ninety. The more rigorously the process of preliminary disintegration above described has been carried out, the shorter the time required for running off the fine sediments, which otherwise tax the operator's patience severely. As a matter of fact they never do give out entirely, doubtless for the reason that the stirrer continues to disintegrate compound particles which had resisted the boiling process. Besides, downward currents on the sides of the vessel *will* form, despite all precautions, so that the interior surface of the cylinder sometimes becomes coated with pendent flakes of coalesced sediment. These must then

from time to time be removed by means of a feather, so as to bring them again under the influence of the stirrer; but it is, of course, almost mathematically impossible that, under these circumstances, any of the sediments subject to coalescence should ever become completely exhausted. Practically, the degree of accuracy attainable at best renders it unnecessary to continue the operation beyond the point when only a milligram or two of sediment comes over with each liter of water. *It is admissible and even desirable to run off rapidly the upper third of the column at intervals of twenty minutes*, whereby not only time is gained, but also the sediment in the relay reservoir is stirred and brought under the influence of the churner for more complete disintegration.

It is noticeable that recent sediments, river-alluvium, etc., are much more easily worked than more ancient ones; as might be expected. Up to 4 mm. hydraulic value the use of the rotary stirrer is indispensable on account of the tendency to the formation of compound particles. Beyond, this tendency measurably disappears, so that for the coarse sediments of 8 to 64 mm. hydraulic stirring may be employed and an elutriating tube of smaller diameter may advantageously be substituted in order to diminish the otherwise somewhat extravagant expenditure of water. The entire amount required for one analysis is from 25 to 30 gallons, provided a thorough previous disintegration has been secured. River water answers in ordinary cases; hard, spring or well waters are undesirable. Distilled water is of course best, and by a simple arrangement of an air-tight reservoir connected with a pressure chamber, can be returned to the Mariotte's bottle and used over and over. The average times required for the several sediments are as follows:

Sediment:	Hours.
0.25 mm.	30 to 40
0.5 mm.	15 to 25
1.0 mm.	5 to 10
2 to 64 mm.	6 to 10
Total	56 to 85

With proper arrangements much of this can be done automatically at night, completing an analysis (except the clay and finest silt determinations) in the course of three or four days. Of course only a very small portion of this time is given by the operator to the care of the instrument. He can carry on other work, just as when an evaporation is going on, with only an occasional glance to see that the water supply holds out and that there is no incipient leakage at the axis.

As the soils are most conveniently weighed "dried at 100°,"* the sediments should be weighed in the same condition. Great care is necessary to obtain the correct weight of the extremely hygroscopic clay. The same is true, more or less, of the <0.25 sediment, which, moreover, is so diffusible in water that it can not readily be collected on a filter. It is best, after letting it subside into as small a compass as possible, to evaporate the last 25–50 cc. in the platinum dish in which it is to be weighed. From the other sediments the water may be decanted so closely as to render their determination easy.

The loss in the analysis of clays and subsoils containing but little organic or other soluble matter is usually from 1.5 to 2 per cent, resulting partially, no doubt, from the loss of the fine silt which comes off, more or less, throughout the process, and is decanted with the voluminous liquid. When the turbidity is marked, it indicates imperfect preliminary disintegration; it may be removed, and the silt collected, by adding a weighed quantity of alum, about 25 milligrams per liter, precipitating with ammonia, and deducting from the weight of the flocculent precipitate the calculated amount of alumina.

The analysis of soils very rich in vegetable matter involves some modifications in the preliminary treatment and final weighings, which are discussed below. Ignition of the soil previous to elutriation, as proposed by some, is obviously inadmissible, as it would render impossible the separation of the clay from the finer sediments.

As heretofore stated (Am. Jour. Sci., Dec., 1872; Proc. Am. Assoc. Adv. Sci., 1872, p. 71), the writer considers that, ordinarily, the investigation of the subsoils is better calculated

*A somewhat clayey soil will continue to lose weight at 100° for five or six days. But after the first six hours the loss becomes insignificant for the purpose in question.

to furnish reliable indications of the agricultural peculiarities of extended regions than that of the surface soils, which are much more liable to local "freaks and accidents," and usually differ from the corresponding subsoils in about the same general points. For practical purposes, therefore, the difficulties incident to the physical analysis of soils rich in humus may in most cases be avoided.

Character of the Sediments.—As regards the size of the particles constituting the successive sediments, the most convenient, because almost universally present, material for reference is quartz sand. Below is a table of measurements in which the values given refer to the largest and most nearly round quartz grains to be found in each sediment. As a matter of course, all sizes between that given and the one next below are to be found in each sediment. A few grains of the finer sediments are also invariably present, owing both to the progressive disintegration of agglomerated particles by the stirrer, and to the inevitable formation of the flocculent aggregates of the finer sediments.

While the measurement of the quartz grains (which are rarely wanting in a soil or clay) affords sufficient landmarks to the scientific observer, it seems desirable to attach to them, besides, generally intelligible designations, which shall approximately, at least, indicate the nature of the sediment. It is not easy to indicate in popular language distinctions not popularly made, but the grades of grain indicated in the common words, grits, sand, and silt, may, if numerically defined, serve at least to establish uniformity of expression among scientific observers and reporters. Thus it might serve a useful purpose to apply the designation of "grits" to all grains above 1 mm. diameter up to "gravel." Below 1 mm. down to 0.1 mm. might be "sand," all below that "silt," viz.: impalpable powders. Then would follow clay, of which the distinctive character is not only impalpable fineness of grain, but also plasticity. To the analyst, however, the designations by hydraulic values will in the nature of the case always remain the most convenient, within the limits of the use of either sedimentation or hydraulic elutriation.

Table of Diameters and Hydraulic Values of Sediments.

	Designation of Materials.	Diameter of Quartz Grains.	Velocity per Second, or Hydraulic Value.
		mm.	*mm.*
1	Grits	1–3	(?)
2	Grits	.5–1	(?)
3	Coarse sand	.50	64
4	Medium sand	.30	32
5	Fine sand	.16	16
6	Fine sand	.12	8
7	Coarse silt	.072	4
8	Coarse silt	.047	2
9	Medium silt	.036	1
10	Medium silt	.025	0.5
11	Fine silt	.016	0.25
12	Fine silt	.010	<0.25
13	Clay	(?)	<0.0023

It is noticeable that the absolute diameter of the elutriator tube exerts a sensible influence on the character of the sediments, in consequence of comparatively greater friction against the sides in a tube of small diameter. Strictly speaking, none of the sediments actually correspond to the velocity calculated from the cross-section of the tube and the water delivered in a given time, but to higher ones, whose maximum is in the axis of the tube, and which gradually decrease towards the sides, according to a

law which may be demonstrated to the eye by slightly diminishing the velocity while a sediment is being copiously discharged, so that the turbid column remains stationary while clear water is running off. The surface then assumes a paraboloid form, which is sensibly more convex in a tube of smaller diameter than in a wide one; the results obtained in the latter being, of course, nearest the truth.

The sediments are conveniently preserved in homeopathic vials of uniform diameter; these, when arranged in a row, show a surface curve from which the prominent features of the physical composition of a soil may be seen at a glance.

DETERMINATION OF THE WATER CAPACITY.

This determination as usually made is very indefinite in its results, varying, especially in pervious soils, according to the height of the soil column in which the water is absorbed. This is due to the obvious fact that at the base of a soil column there is a maximum of this factor, decreasing regularly towards the top of the column, where it becomes a minimum. Now since the total ascent of water in columns of different soils varies from less than 375 mm. to over 2,800 mm., it is clear that any given uniform height of column arbitrarily agreed upon, as proposed by Ad. Mayer and others (*e. g.*, 60 or 200 mm.), will give results standing in no direct rational relation to the maxima and minima of absorption by different soils. (See Wollny's Fortschr. Agr. Physik, 15, 1.)

It is evident that in this case, as in others, either a maximum or a minimum determination, or both, should be agreed upon; and such determination should be made in soil columns of as little height as possible; that is, approaching as nearly as may be to the theoretical postulate of a mere differential. I suggest as the lowest practicable measure for this purpose a column of 10 mm., placed in a circular brass box with perforated bottom, resembling the lead sieve of Plattner's blowpipe chest, and containing exactly 25 or 50 cc. In this both the maximum and minimum absorption is determined for each soil, proceeding as follows:

Fill the box full of air-dried soil, of which the moisture content is determined in a separate portion at 100°. Settle the soil by a gentle tapping of the box on a table and then "strike" it level as in measuring grain; weigh.

Place the weighed box, plus soil, on a triangle submerged just beneath the surface of the water in a somewhat wide vessel; allow it to stand until fully saturated (not less than an hour, in order to insure the complete wetting of compacted soil particles); then wipe the sieve surface rapidly with filter paper or an absorbent towel and weigh again without unnecessary delay. Calculate from the weighings the *maximum* of water capacity with respect to both weight and volume. Now place the same vessel with wet soil on a flat desiccator plate, and immediately cover it with an additional (unweighed) quantity of the same soil, in order to absorb all the water down to the minimum of liquid absorption.

The desiccator plate, as well as the bell covering it, must be lined with wetted blotting paper in order to maintain a fully saturated atmosphere; and during the latter portion of the process of minimization at least, the soil used must itself have been previously exposed to such an atmosphere long enough to fully saturate it with hygroscopic moisture (see below), since otherwise such moisture would be taken up from the wetted soil and would thus vitiate the determination of liquid water capacity. A counterpoised glass plate on the scale pan of the balance serves to cover the soil cylinder while weighing.

After the soil above has become imbued with moisture it is cut off level with the edges of the box by means of a tense, fine silk thread. The upper portion being thrown off, the operation is repeated until the fresh quantities of soil fail to become moistened above the edge of the box and cease to adhere, and weight ceases to decrease materially. Lastly, blow off carefully any loose particles remaining on the surface, and weigh. Dry the earth in the box thoroughly at 100°; weigh. The water thus driven off will represent the *minimum* of liquid absorption plus the hygroscopic moisture originally contained in the soil, as previously determined by drying at 100°. The soil mass will, as a rule, be found somewhat greater than that calculated from the first determination, because the unavoidable jarring and the weight of the soil poured on the wet mass compacts the latter to some extent.

By simple calculation the results may be referred to either of the two quantities for water capacity both by weight and volume, allowing for the increase of weight.

It is clear that the soil so depleted of the water held in liquid absorption down to the minimum is in precisely the same condition as a similar layer of soil forming the top of a soil column in which the water has been allowed to rise to its maximum height by capillary ascent. It seems at least probable that hereafter we may be able to deduce from these determinations the absolute height to which water will rise in a soil column in the course of time; but thus far we have no formula for such a deduction. Wollny has shown (Forsch. Agr. Physik, 8, 197) that, as a general rule, the differences between the maxima and minima become less as the soil becomes more fine-grained; and this difference becomes an important physical datum in judging of the capillary efficiency of the soil. We can then by the above method attain in two or three days results which by direct trial would require at least as many months; and the differences between the maxima and minima thus ascertained far exceed those thus far on record.

METHOD OF CHEMICAL SOIL ANALYSIS.

The methods of chemical soil analysis hereinafter given are essentially those which in their main features have been pursued by Drs. David Dale Owen and Robert Peter in the work of the geological surveys of Kentucky and Arkansas, and which have since been further developed by the writer in the soil work of the surveys of Mississippi and Louisiana; in that done in connection with the Tenth Census "Report on cotton culture" throughout the cotton States; in that of the Transcontinental Survey, in the States of Oregon, Washington, and Montana; and in the soil work of the California experiment station. Altogether these methods of soil investigation have been applied to over a thousand virgin soils, the analyses of which are strictly comparable among themselves; therefore by far the largest uniform set in existence thus far. Considering the labor involved in the work so performed, it becomes a serious question whether there are any valid reasons why the methods employed in it should be changed in any essential points, since to do so would throw out of any possible comparison with future work the bulk of what has heretofore been done in soil investigation on the North American continent.

It is for this reason that the methods are given in considerable detail, not with a view of contesting the validity or equal reliability of other processes, but in order that every possible objection may now be raised, before more work shall be placed in jeopardy of being thrown out of comparison by a change of methods. Their convenience and substantial accuracy within the limits of personal error having been tested by considerable experience, and the mode of interpreting the analytical results so as to accord with the farmers' experience in cultivation having been developed with respect to analyses made in accordance therewith, there should be strong reasons for changing the methods before such action is finally taken. In most respects the course of analysis here presented does not differ materially from that laid down by Kedzie in his report on the same subject; the chief differences arise in the preliminary operations, but are there quite vital, so as to necessitate an agreement if the comparability of analyses is to be maintained.

It should be understood that these methods contemplate *an approximation to the total maximum of solvent effect plants can exert upon the soil;* carbonated water being by far too feeble as a solvent to represent even ordinary plant action, while hydrofluoric acid and fusion with alkalies go far beyond vegetative possibilities. It is certainly desirable that the limit of extraction should be a *natural* one rather than an arbitrary convention, which many chemists will be inclined to disregard when it manifestly does not fit the case before them. Experiments have shown that soils extracted with strong chlorhydric acid are permanently * sterile; and if it can be shown that the results obtained from such soil extraction can be readily correlated with the *permanent agricultural value* of soils, the most important postulate of soil analysis is covered.

PRELIMINARY PREPARATION OF THE SAMPLE.

The soil is thoroughly broken up, dry, with a rubber pestle; or in the case of clayey soils is digested with distilled water until fully disintegrated. A weighed quantity

* *i. e*, within the time interesting to the living generation.

(200 to 500 grams) is then sifted or washed, as the case may be, through a sieve of 0.5 mm. clear aperture. If washed, the muddy water must be evaporated to dryness with the soil slush and the whole thoroughly mixed. The sample so obtained constitutes the "fine earth" to be used in chemical analysis. The coarse portions are to be further segregated by sieves, weighed, and their mineralogical constituents identified with the microscope, reagents, or Thoulet's solution, as the case may require.

That the introduction of the grain-sizes coarser than 0.5 mm. can as a rule serve no useful purpose in the chemical analysis of soils in the *humid region* is strikingly shown in the investigation made by R. H. Loughridge, in 1873 (Am. J. Sci., Jan. 1874, p. 17). He found that in the case of a very generalized soil of the Mississippi uplands, solution by strong acid practically ceased beyond the sediment of 0.5 mm. hydraulic value, corresponding to a diameter of about 0.025 mm. Although the general applicability of this particular limit may be fairly questioned, the wide margins between the fractions 0.5 and 0.025 renders it pretty certain that within the limit of the former we shall find all that is of any value to plants for their supply of mineral plant food. But for the sake of comparability with analyses made under a different rule, the grain-sizes of 0.5 to 1 and 1 to 2 mm. diameter should always be quantitatively determined.

It is true that in the *arid region* the larger grains contribute to plant nutrition, being themselves covered with a partially decomposed soil material. The investigations of Tolman* have, however, shown that such material is of the same general composition as the fine earth. If it be desired to make allowance for this fact by including the larger grain-sizes, it would be necessary to employ a correspondingly larger amount of soil for general analysis.

DETERMINATION OF THE HYGROSCOPIC COEFFICIENT.

The fine earth is exposed to an atmosphere saturated with moisture for about twelve hours at the ordinary temperature (60° F.) of the cellar in which the box should be kept. For this it is sifted in a layer of about 1 mm. thickness upon glazed paper, on a wooden table in a small water-tight covered box (12 by 9 by 8 inches) in which there is about an inch of water; the interior sides and cover of the box should be lined with blotting paper, kept saturated with water, to insure the saturation of the air.

"Air-dried soil" yields results varying from day to day to the extent of as much as 30 to 50 per cent, nor have we any corrective formula that would reduce such observations to absolute measure. Knop's law, that the absorption varies directly as the temperature, while applicable to low percentages of saturation, is wide of the truth when saturation is approached. The observation of the writer has shown that between the temperatures of about 7 and 23° C. the coefficient of absorption in saturated air varies only by a small fraction; hence the ordinary temperature of cellars will serve well in these determinations without material correction.

After eight to twelve hours the earth is transferred as quickly as possible, in the cellar, to a weighed drying-bottle and weighed. The bottle is then placed in an air bath, the temperature of which is gradually raised to 110° C. and kept so for one hour. It is then weighed and the drying repeated until a practically constant weight is obtained. The loss in weight gives the hygroscopic moisture in saturated air.

GENERAL ANALYSIS.

The samples for general analysis and phosphoric acid determination are weighed out from the air-dried sample in which the hygroscopic moisture is afterward determined.

In determining the amount of material to be employed for the general analysis regard must be had to the nature of the soil. This is necessary because of the impracticability of handling successfully such large precipitates of alumina as would result from the employment of even as much as 5 grams in the case of calcareous clay soils; while in the case of very sandy soils even that quantity might require to be doubled in order to obtain weighable amounts of certain ingredients. For average loam soils in which the insoluble portion ranges from 60 to 80 per cent, 2.5 to 3 grams is about the right measure for general analysis, while for the phosphoric acid determination not less than 3 grams should be employed in any case. It has been alleged that larger quanti-

* Report of the California Experiment Station for 1899–1900, page 33.

ties must be taken for analysis in order to secure average results. It is difficult to see why this should be true for the fine earth of soils and not for ores, in which the results affect directly the money value; while in the case of soils the interpretation of results allows much wider limits in the percentages. Correct sampling must be presupposed to make any analysis useful; but with modern balances and methods it is difficult to see why 5 grams should be employed instead of half that amount, which in some cases is still too much for convenient manipulation of certain precipitates unless parting into aliquot portion is resorted to; which in the case of the iron-alumina precipitation would be very desirable, but can not usefully be carried out in practice. It is very much more difficult to secure a correct average sample when the coarser sizes of sand, such as 1–2 mm. diameter, are retained in the fine earth, as these tend to settle down out of the finer portions. If, then, these larger sizes are insisted upon, 10 or more grams must be employed in order to secure a fair average sample.

(1) The weighed quantity, usually of 2 to 2.5 grams, is brought into a small porcelain beaker covered with a watch glass, treated with 8 to 10 times its bulk of hydrochloric acid of 1.115 sp. gr. and 2 or 3 drops of nitric acid, and digested for five days over the laboratory steam bath. At the end of this time it is evaporated to dryness, first on the water bath and then on the sand bath. By this treatment all the silica set free is rendered insoluble.

In an investigation made by Loughridge in 1873 (Am. J. Sci., Jan., 1874, p. 20) it was found that acid of the above strength exerted a higher solvent power than that materially stronger or weaker (1.100 or 1.160 sp. gr.). He also found that after the fifth day no further essential solvent action occurred. The above standard strength is easily prepared by steam distillation of acid either stronger or weaker. Later investigations by Jaffa show that the effect of such acid approximates closely to that of oxalic acid, the strongest solvent available for plant-root action. We therefore determine in such treatment the maximum effect vegetation can exert on soils.

The evaporation residue is now moistened with strong hydrochloric acid and 2 or 3 drops of nitric acid, warmed, and, after allowing it to stand a few hours on the water bath, treated with distilled water. After clearing it is filtered from the *insoluble residue*, which is strongly ignited and weighed. If the filtrate should be turbid the insoluble residue which has gone through the filter can be recovered in the iron-and-alumina determination.

The insoluble residue is next boiled for fifteen or twenty minutes in a concentrated solution of carbonate of soda, to which a few drops of caustic lye should then be added, to prevent reprecipitation of the dissolved silica. The solution must be filtered hot. The difference between the weight of the total residue and that of undissolved sand and mineral powder is recorded as *soluble silica*, being the aggregate of that set free by the acid treatment and that previously existing in the soil. The latter, however, rarely reaches 0.5 per cent.

(2) The acid filtrate from the total insoluble residue is evaporated to a convenient bulk. In case the filtrate should indicate by its color the presence of any organic matter, it should be oxidized by aqua regia, otherwise there will be difficulty in separating alumina.

(3) The filtrate thus prepared is now brought to boiling and treated sparingly with ammonia, whereby *iron and alumina* are precipitated. It is kept boiling until the excess of ammonia is driven off, and then filtered hot (Mitscherlich method). (Filtrate A.) The previous addition of ammonic chlorid is usually unnecessary. If the boiling is continued too long, filtration becomes very difficult, and a part of the precipitate may redissolve in washing. Filtration may be begun so soon as the nose fails to note the presence of free ammonia; test paper is too delicate. Failure to boil long enough, or permitting the precipitated solution to cool, involves the contamination of the iron-alumina precipitate with lime and manganese.

(4) The *iron and alumina* precipitate (with filter) of No. 3 is dissolved in a mixture of about 5 cc. hydrochloric acid and 20 cc. water. Then filter and make up to 150 cc. Take 50 cc. for the determination of iron and alumina together by precipitation with ammonia, after oxidizing the organic matter (filter) with aqua regia; also 50 cc. for iron alone; keep 50 cc. in reserve. Determine the *iron* by means of a standard solution of permanganate of potash after reduction; this latter is done by evaporating the 50 cc.

almost to dryness with strong sulfuric acid, adding water and transferring the solution to a flask, and then reducing by means of pure metallic zinc in the usual way. The *alumina* is then determined by difference. This method of determining the two oxids in their intermixture is in several respects more satisfactory than the separation with alkaline lye, which, however, has served for most determinations made until within the last twenty years. It is much more liable to miscarry in unpracticed hands than the other.

(5) The filtrate A from iron and alumina is acidified slightly with HCl, and if too bulky is evaporated down to about 25 cc. (unless the soil is a very calcareous one) and the *lime* precipitated from it by neutralizing with ammonia and adding ammonic oxalate. The precipitation of the lime should be done in the hot solution, as the precipitate settles much more easily. It is allowed to stand for twelve hours, then filtered off, washed with cold water, and dried (filtrate B). By ignition the lime precipitate is partially converted into the oxid. It is then heated with excess of powdered ammonium carbonate, moistened with water, and exposed to a gentle heat (50°-80° C.) until all the ammonia is expelled. It is then dried below red heat and weighed as lime carbonate. When the amount of lime is at all considerable, the treatment with ammonic carbonate must be repeated until a constant weight is obtained.

(6) The filtrate B from the calcic oxalate is put into a hard Bohemian or Jena flask, boiled down over the sand bath and the ammoniacal salts destroyed with aqua regia (Lawrence Smith's method). From the flask it is removed to a small beaker and evaporated to dryness with excess of HNO_3. This process usually occupies four to five hours. The residue should be crystalline-granular; if white-opaque, ammonic nitrate remains and must be destroyed by HCl.

The dry residue is now moistened with nitric acid and the floccules of silica usually present separated by filtration from the filtrate, which should not amount to more than 10 or 15 cc. *Sulfuric acid* is then precipitated by treatment with a few drops of baric nitrate, both the solution and the reagent being heated to boiling. If the quantity of SO_3 is large, it may be filtered off after the lapse of four or five hours. If very small, let it stand twelve hours. The precipitate is washed out with boiling water, dried, ignited, and weighed (filtrate C). Care should be taken in adding the barium nitrate to use only *the least possible excess*, because in such a small concentrated acid solution the excess of barium nitrate may crystallize and will not readily dissolve in hot water. Care must also be taken not to leave in the beaker the large heavy crystals of baric sulfate, a few of which sometimes constitute the entire precipitate, rarely exceeding a few milligrams. Should the ignited precipitate show an alkaline reaction on moistening with water, it must be treated with a drop of HCl, refiltered and weighed. The use of barium acetate involves unnecessary trouble in this determination.

(7) Filtrate C from SO_3 precipitate is now evaporated to dryness in a platinum dish; the residue is treated with an excess of crystallized oxalic acid, moistened with water, and exposed to gentle heat. It is then ignited to change the oxalates to carbonates. This treatment with oxalic acid must be made in a vessel which can be kept well covered with a thin watch glass, otherwise there is danger of loss through spattering. As little water as possible should be used, as otherwise loss from evolution of carbonic gas is difficult to avoid. Spatters on the cover should not be washed back into the basin until after the excess of oxalic acid has been volatilized. The ignited mass should have a slightly blackish tinge to prove the conversion of the nitrates into carbonates. White portions may be locally retreated with oxalic acid. The ignited mass is treated with a small amount of water, which dissolves the alkali carbonates and leaves the carbonates of magnesia, protosesquioxid of manganese, and the excess of barium carbonate behind. The *alkalies* are separated by filtration into a small platinum dish (filtrate D), and the residue is well but economically washed with water on a small filter. When the filtrate exceeds 10 cc., it may on evaporation show so much turbidity from dissolved earthy carbonates as to render refiltration on a minute filter necessary, since otherwise the soda percentage will be found too large, magnesia too small. If on dissolving the ignited mass the solution should appear greenish from the formation of alkaline manganates, add a few drops of alcohol to reduce the manganese to insoluble dioxid. The residue of barium, magnesium, and manganese compounds is treated on the filter with hydrochloric acid, and the platinum dish is washed with warm nitric acid (not hydro-

chloric, for the platinum dish may be attacked by chlorin from the manganese oxid), dissolving any small traces of precipitate that may have been left behind.

(8) The solution containing the chlorids of magnesium and manganese is freed from the barium salts by hot precipitation with sulfuric acid, and the barium sulfate after settling a few hours is filtered off. The filtrate is neutralized with ammonia, any resulting small precipitate (of iron) is filtered off, and the *manganese* precipitated with bromine water. Let stand twelve hours (or over night) and filter (filtrate E); wash with cold water, dry, ignite, and weigh as manganese protosesquioxid Mn_3O_4.

(9) From the filtrate E (from the manganese), the *magnesia* is precipitated by adding an equal bulk of ammonia water and then sodic phosphate. After standing at least twenty-four hours, the magnesia salt may be filtered off, washed out with ammoniacal water, dried, ignited, and weighed as magnesium pyrophosphate.

(10) The filtrate E, which should not be more than 10 or 15 cc., containing the carbonates of the *alkalies*, is evaporated to dryness and gently fused, so as to render insoluble any magnesium carbonate that may have gone through; then redissolved and filtered into a small weighed platinum dish containing a few drops of dilute hydrochloric acid, to change the carbonates into chlorids; evaporated to dryness, exposed to a gradually rising temperature (below red heat), by which the chlorids are thoroughly dried and freed from moisture, so as to prevent the decrepitation that would otherwise occur on ignition. Then, holding the platinum basin firmly by forceps grasping the clean edge, pass it carefully over a very low Bunsen flame, so as to cause, successively, every portion of the scaly or powdery residue to collapse, without fully fusing. There is thus no loss from volatilization, and no difficulty in obtaining an accurate, constant weight. The weighed chlorids are washed by means of a little water into a small beaker or porcelain dish, treated with a sufficient quantity of platinic chlorid, and evaporated to dryness over the water bath. The dried residue is treated with a mixture of 3 parts absolute alcohol and 1 part ether, leaving the potassio-platinic chlorid undissolved. This is put on a filter, and washed with ether-alcohol. When dried, the precipitate and filter are put into a small platinum crucible and exposed to a heat sufficiently intense to reduce the platinum chlorid to metallic platinum and to volatilize the greater part of the potassium chlorid. This is easily accomplished in a small crucible, which is roughened by being constantly used for the same purpose (and no other), the spongy metal causing a ready evolution of the gases. (See Fres. Ztschr. anal. Chem., 1893.) The reduced platinum, which should adhere firmly to the crucible after ignition over a blast lamp for twenty minutes, is now first washed in the crucible with hot acidulated water, then with pure water; then all moisture is driven off and it is weighed. From the weight of the platinum is calculated the *potassic chlorid* and the oxid corresponding; the difference between the weights of the total alkali chlorids and potassic chlorid gives the sodic chlorid, from which may be calculated the *sodic oxid*. When the heating of the platinum precipitate has not been sufficient in time or intensity, instead of being in a solid spongy mass of the color of the crucible itself, small black particles of metallic platinum will obstinately float on the surface of the water in the crucible, and it becomes difficult to wash by decantation without loss.

PHOSPHORIC ACID DETERMINATION.

(11) The weighed quantity (usually of 3 to 5 grams) is ignited in a platinum crucible, care being taken to avoid all loss by dusting. The loss of weight after full ignition gives the amount of chemically-combined water and volatile and combustible matter.

(12) The ignited soil is now removed to a porcelain or glass beaker, treated with four to five times its bulk of strong nitric acid, digested for two days, evaporated to dryness first over the water bath and then over the sand bath, moistened with nitric acid, heated and treated with water. After standing a few hours on the water bath it is filtered off from the insoluble residue and the filtrate is evaporated to a very small bulk (10 cc.), and treated with about twice its bulk of the usual ammonium molybdate solution, thus precipitating the phosphoric acid. After standing at least twelve hours, at first at a temperature of about 50° C., it is filtered off and washed with a solution of ammonium nitrate acidified with nitric acid. The washed precipitate is dissolved on the filter with dilute ammonia water. After washing the filter carefully the ammoniacal solution is

treated with magnesia mixture, by which the phosphoric acid is precipitated. After allowing it to stand twenty-four hours it is filtered off, washed in the usual way, dried, ignited, and weighed as magnesium pyrophosphate, from which the phosphoric acid is calculated. The per cent of phosphoric acid found is to be subtracted from that of the alumina. When a gelatinous residue remains on the filter after dissolving the molybdophosphate with ammonia it may consist either of silica not rendered fully insoluble in the first evaporation, or, more rarely, of alumina containing phosphate. It should be treated with strong nitric acid, and the filtrate with ammonic molybdate; any precipitate formed is of course added to the main quantity before precipitating with magnesia solution.

HUMUS DETERMINATION IN SOILS.

The estimation of "humus" by combustion, in any form, of the *total* organic matter in the soil gives results varying according to the season, and having no direct relation to the active humus of the soil. The same objection lies against extraction with strong caustic lye, which quickly humifies additional organic matter present. To obtain an estimate of the humus actually active in plant nutrition through nitrification, we must eliminate the unhumified organic matter. The best mode for accomplishing this, thus far known, is:

GRANDEAU'S METHOD.

About 10 grams of soil is weighed off into a prepared filter. The soil should be covered with a piece of paper (a filter) so as to prevent it from packing when solvents are poured on it. It is now treated with hydrochloric acid from 0.5 per cent to 1 per cent strong (25⅓ cc. of strong acid and 808 cc. of water) to dissolve out the lime and magnesia which prevent the humus from dissolving in the ammonia. Treat with the acid until there is no reaction for lime; then wash out the acid with water to neutral reaction. Dissolve the humus with weak ammonia water, prepared by diluting common saturated ammonia water (178 cc. ammonia to 422 cc. water). Evaporate the humus solution to dryness in a weighed platinum dish at 100° C.; weigh, then ignite; the loss of weight gives the weight of humus, the *matière noire* of Grandeau.

The examination of the ash of this humus, which contains notable amounts of phosphoric acid, potash, lime, and magnesia, does not appear to offer sufficient information to justify its analysis in ordinary cases.

DETERMINATION OF NITROGEN IN SOILS.

The humus determination has been thought to indicate approximately the store of nitrogen in the soil, which must be gradually made available by nitrification. Ordinarily (outside of the arid regions) the determination of ammonia and nitrates present in the soil is of little interest for general purposes, since these factors will vary with the season and from day to day. Kedzie (in the report above quoted) proposes to estimate the active soil nitrogen (ammonia plus nitrates and nitrites) by treatment of the whole soil with sodium amalgam and distillation with lime. The objection to this process is that the formation of ammonia by the reaction of the alkali and lime upon the humus amides would greatly exaggerate the active nitrogen and lead to a serious overestimate of the soil's immediate resources.

The usual estimate of nitrogen in black soil-humus (Grandeau's *matière noire*, determined as above) is from 5 to 6 per cent in the regions of summer rains. From late determinations it would seem that in the arid regions the usually small amount of humus (often less than 0.20 per cent) is materially compensated by a materially higher nitrogen percentage. It thus becomes necessary to determine the humus-nitrogen directly; and this is easily done by substituting in the Grandeau process of humus-extraction, potash or soda lye for ammonia water, and determining the nitrogen by the Kjeldahl method in the filtrate. While it is possible that the ammonia water would not vitiate the determination of nitrogen in the case of neutral or calcareous soils, it would certainly do so in the case of those having an acid reaction.

The lye used should have the strength of 4 per cent in the case of potassic hydrate, 3 per cent in that of sodic hydrate. The black humus filtrate or an aliquot part is placed in the Kjeldahl flask with concentrated sulfuric acid, and the nitrogen determined in the usual way.

To this method the objection has been made that the "humus" extracted by fixed alkalies is not necessarily the same as that dissolved by ammonia. This objection may be obviated by extracting two separate portions (of 10 grams) of the soil with ammonia, as above, and using the one for the determination of total humus; while the other, after evaporation to small volume, is mixed with about 5 per cent of magnesic oxid, which in boiling eliminates all the ammonia that has been taken up from the ammoniacal solvent; after which the nitrogen in the residue is determined by the usual Kjeldahl method. The results obtained by these two methods, however, usually agree very closely.

For the determination of nitrates in the soil it is, of course, usually necessary to use large amounts of material, say not less than 50 grams and, according to circumstances, five or more times that amount. In the evaporated solution the nitric acid is best determined by the reduction method, as ammonia.

Usually the soil-filtrate is clear and contains no appreciable amount of organic matter that would interfere with the determination; yet in the case of alkaline soils (impregnated with carbonate of soda) a very dark-colored solution may be obtained. In that case the soil may advantageously be mixed with a few per cent of powdered gypsum before leaching; or the gypsum may be used in the filtrate to discolor it by the decomposition of sodic carbonate and the precipitation of calcic humate. The evaporated filtrate can then be used for the nitrate determination by either the Kjeldahl, Sprengel, or the colorimetric method, which will, of course, include such portions of the ammoniacal salts as may have been leached out.

For the separate determination of these and of the occluded ammonia, when desired, it is probably best to mix the wetted soil intimately with about 10 per cent of magnesic oxid and distill off into titrated chlorhydric acid. For general purposes, however, this determination is usually of little interest.

DETERMINATION OF "PROBABLY AVAILABLE PLANT FOOD."
(Dyer's Method.)

The methods of chemical soil analysis discussed in the preceding pages are intended to show the entire amount of mineral plant food likely to become available within the time interesting to the present and several succeeding generations, with a view to permanent investments. In the case of virgin soils the adequate availability of these ingredients, and the consequent duration of productiveness, may usually be assumed to be in more or less direct proportion to the total amounts found. But in the case of soils long cultivated, it is extremely desirable to ascertain somewhat definitely the present needs of the soil, so as not to waste money on the purchase of unnecessary fertilizers. Numerous methods for this purpose have been suggested, from the extraction with large amounts of pure water to that with dilute chlorhydric acid, and various salts. Of all these methods none seems to accord so nearly with the results of practical culture as the extraction of the soil with a 2 per cent solution of citric acid, originally suggested by Maerker, and later more definitely developed by Dr. Dyer, whose name the method usually bears. Dyer's method, somewhat modified to conform to the conditions of the arid region, is as follows:

Place in a flask, or bottle, 100 grams of air-dried soil and 600 cc. of distilled water containing 12 grams of pure citric acid. (Whenever the soil contains carbonates, a proper allowance must be made for them by a corresponding increase in the dose of citric acid.) The soil is left at room temperature in contact with the 2 per cent solution of citric acid for twenty-four hours, with frequent thorough shaking. At the end of the digestion the solution is filtered, and divided into three parts—one for the potash, and one for the phosphoric acid determination, the third as a reserve. Evaporate each to dryness, ignite, and determine the potash and phosphoric acid according to the methods given above for the general analysis of the soil.

PRESENTATION AND INTERPRETATION OF RESULTS.

It is strenuously suggested that in the presentation of the results of a soil analysis the order of the electrolytic series be observed, as in the schedule annexed, so as to

facilitate comparisons which are rendered unnecessarily troublesome by differences in arrangement. The insoluble residue is best placed at the head of the column, as it indicates at a glance, approximately, the general character of the soil as sandy, loamy, or clayey.

Coarse materials $>0.50^{mm}$	
Fine earth	
	100.00

Chemical Analysis of Fine Earth.

Insoluble matter	
Soluble silica	
Potash (K_2O)	
Soda (Na_2O)	
Lime (CaO)	
Magnesia (MgO)	
Br. ox. of Manganese (Mn_3O_4)	
Peroxid of Iron (Fe_2O_3)	
Alumina (Al_2O_3)	
Phosphoric acid (P_2O_5)	
Sulfuric acid (SO_3)	
Carbonic acid (CO_2)	
Water and organic matter	
Total	
Water-soluble matter, per cent	
Chlorin, per cent	
Humus	
" Ash	
" Nitrogen, per cent in Humus	
" " per cent in Soil	
Available Potash { citric acid method }	
Available Phosphoric Acid { citric acid method }	
Hygroscopic moisture, absorbed at —— ° C.	

Water capacity:	By Volume.	By Weight.
Maximum		
Minimum		

For suggestions concerning the interpretation of analyses made according to the above methods, see "Report on the Experiment Station of the University of California," 1890, pages 151 to 172.